Accelerating the next technology revolution

Level-specific material evaluations for NXE3300 applications

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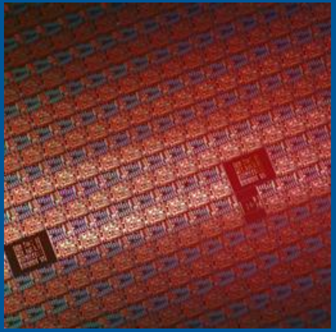
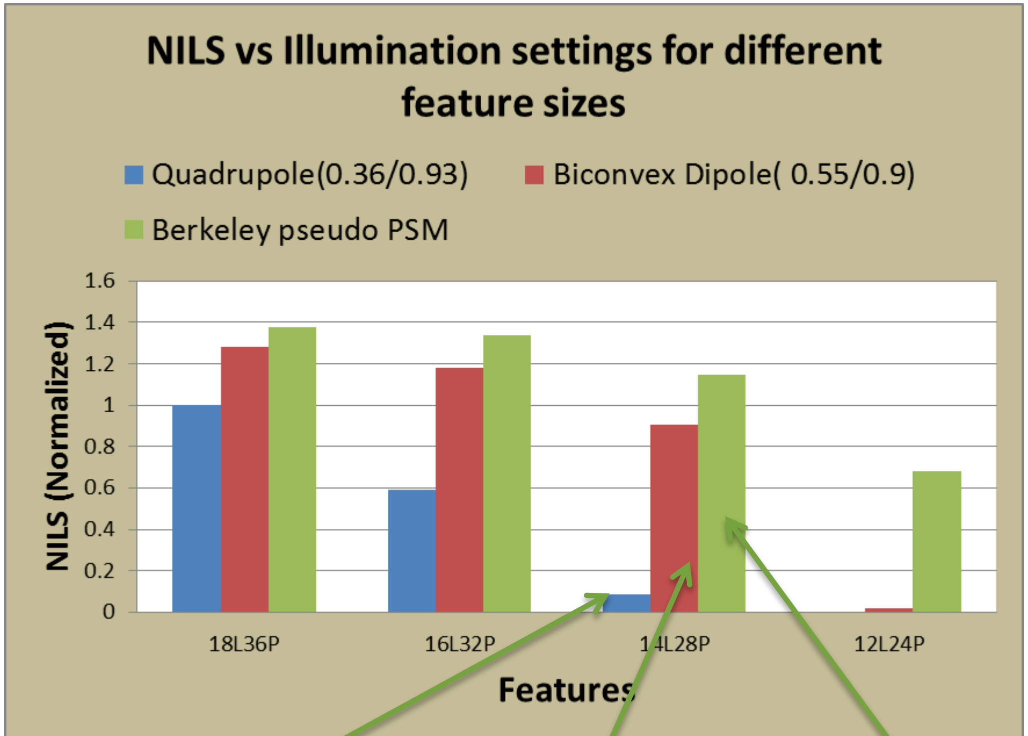


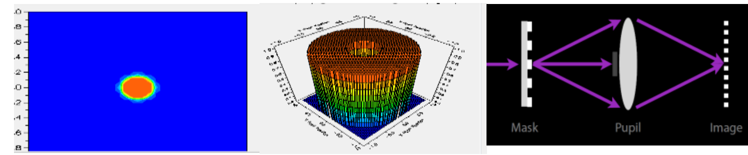
Agenda

- Introduction
- Line/space applications
  - Exposure tool: Albany MET with bi-convex dipole
- Contact and via applications
  - Exposure tool: ADT
- 2D imaging
  - Exposure tool: Albany MET with quadrupole illumination
- LWR and pattern collapse improvement
  - Exposure tool: ADT
- Defect reduction
  - Exposure tool: ADT
- Summary

Normalized Image log slope

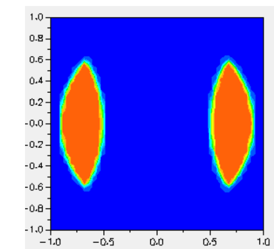


Berkeley MET

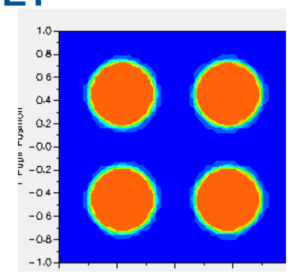


Central obscuration on objective lens: 2-beam imaging: pseudo PSM

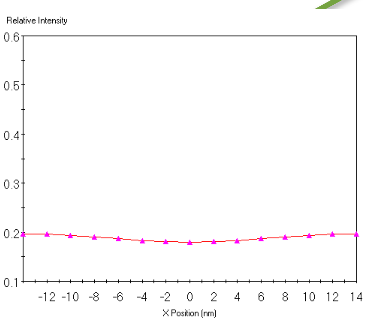
Albany MET



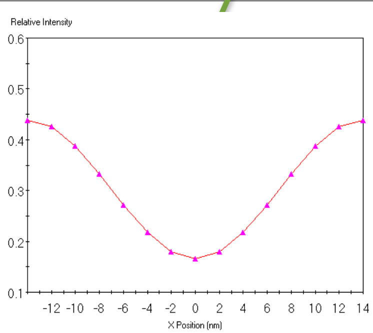
Biconvex dipole(sigma =0.55/0.9)



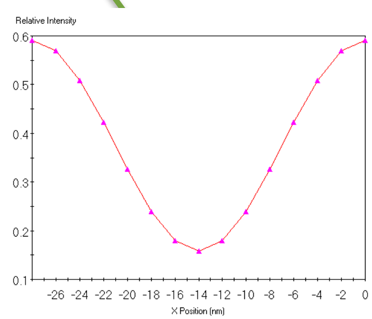
Quadrupole=0.36/0.93)



Quadrupole : 14L28P



Biconvex dipole : 14L28P



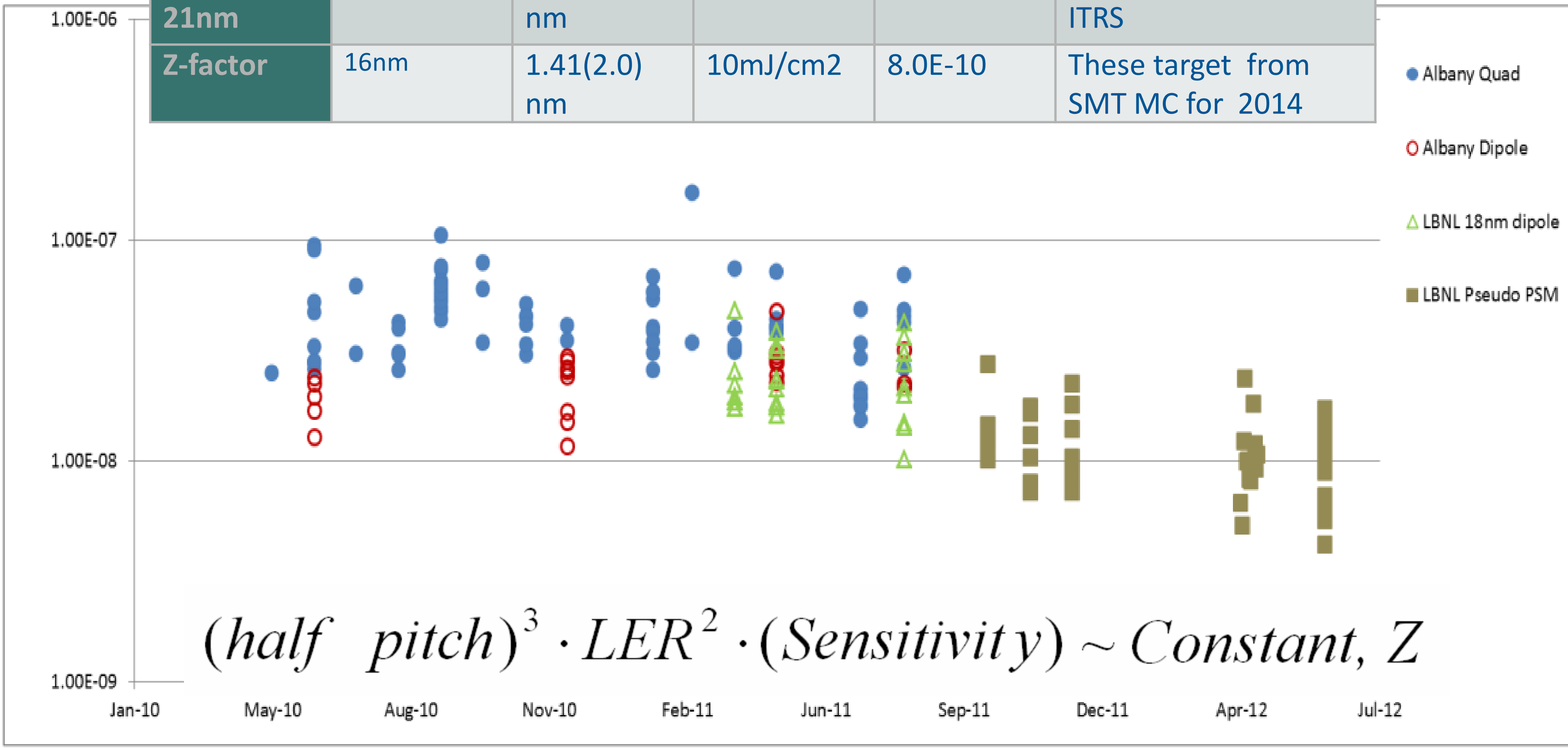
Berkeley Exposure: 14L28P

For 14nm L/S or below, Biconvex or Pseudo PSM is needed.

Z Value of EUV resists over time

(for lines and spaces)

	Resolution	LER(LWR)	Sensitivity	Z-factor	Comment
MPU Gate 21nm	21nm	1.27(1.8) nm	10mJ/cm2	1.5E-09	These number from ITRS
Z-factor	16nm	1.41(2.0) nm	10mJ/cm2	8.0E-10	These target from SMT MC for 2014



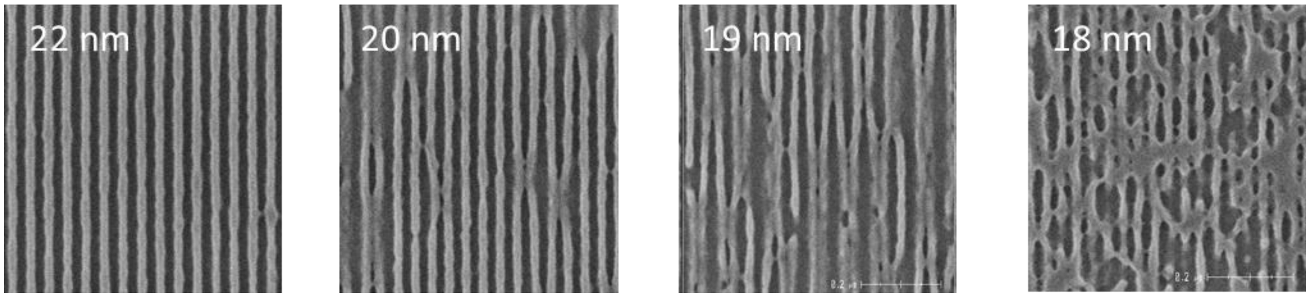
$$(half\ \ pitch)^3 \cdot LER^2 \cdot (Sensitivity) \sim Constant,\ Z$$

- Data represents materials from six suppliers
- Mostly improvement in Z value comes from improving the aerial image
- Some progress in Z value due to the resist improvements is evident
- Data here is not exactly comparable to ITRS roadmap values due to differences in half pitch and LER measurement details

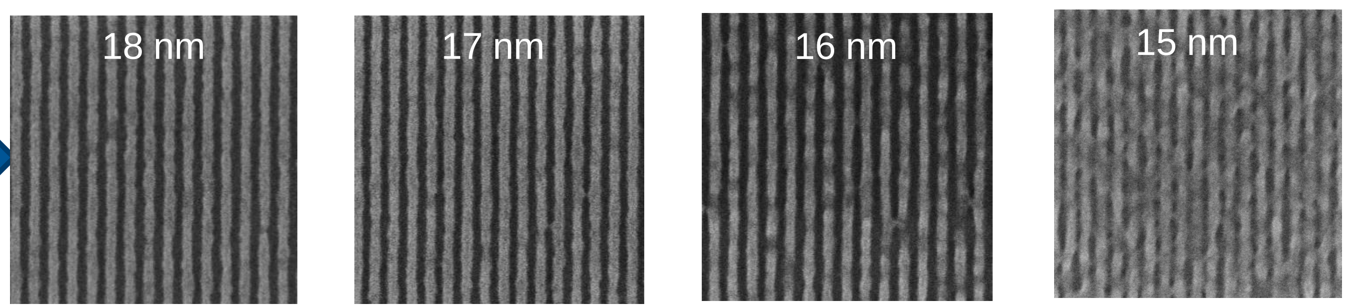
Agenda

- **Line/space**
  - **Exposure tool: Albany MET with bi-convex dipole illumination**
- Contact and via on ADT
- 2D imaging
- LWR and pattern collapse improvement
- Defect reduction

16 nm hp with bi-convex dipole



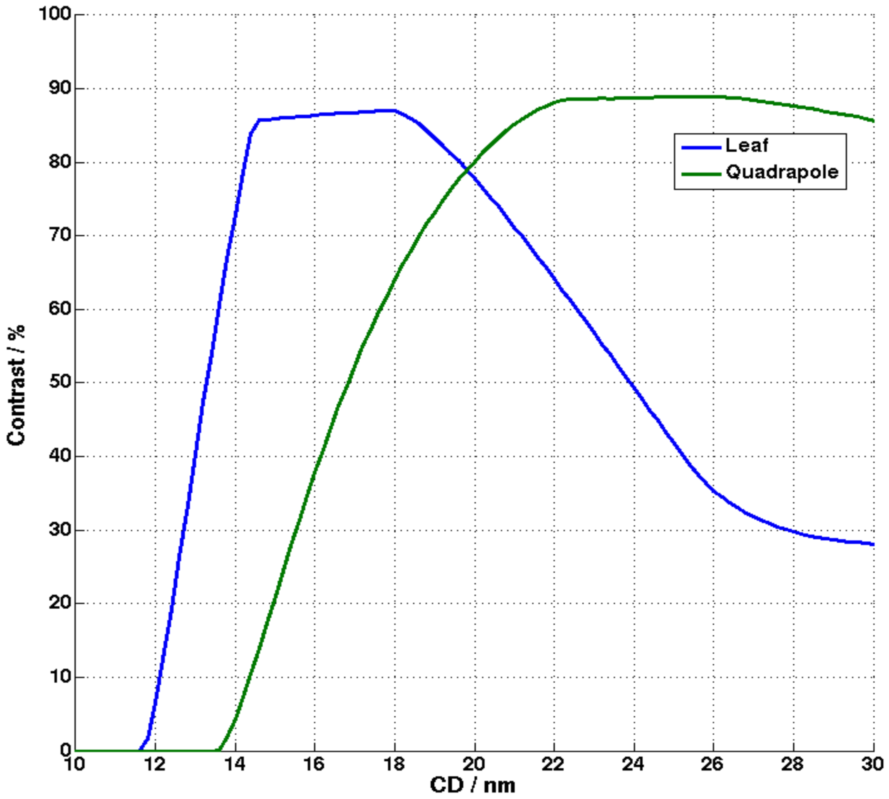
Old illuminator
0.36/0.68 dipole



New illuminator
0.55/0.93 dipole

16 nm hp imaging capability has been achieved using bi-convex dipole

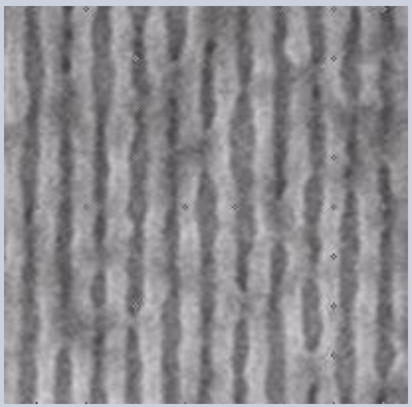
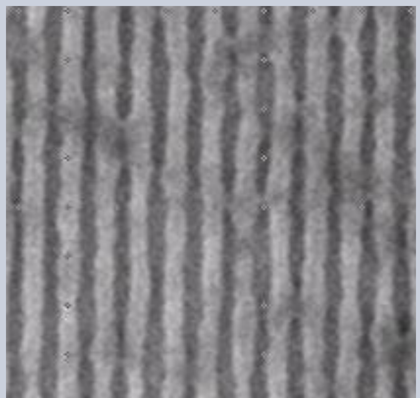
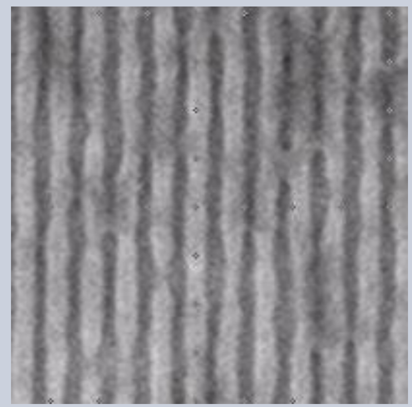
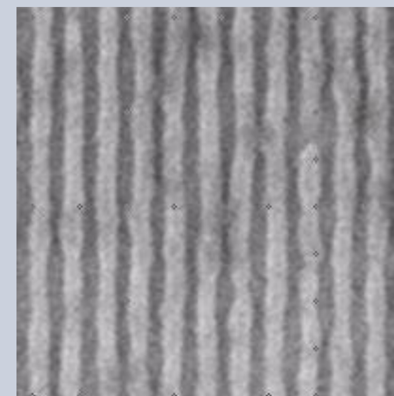
Recommended illumination settings



- Quadrupole (0.36/0.93)
  - CH and L/S 50 nm – 20 nm
- Bi-convex dipole (0.55/0.93)
  - L/S 20 nm and below

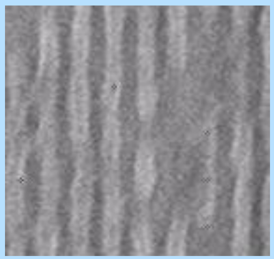
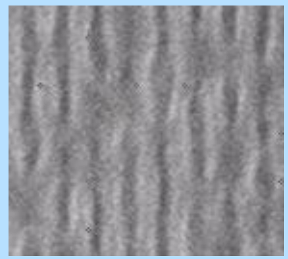
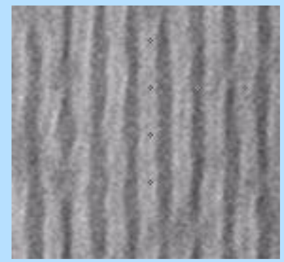
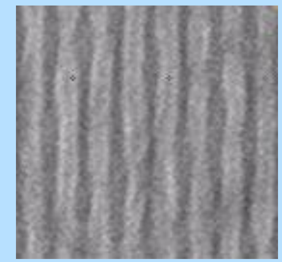
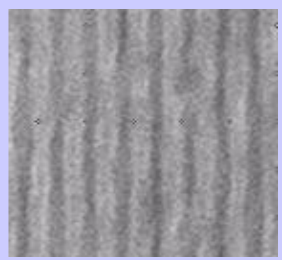
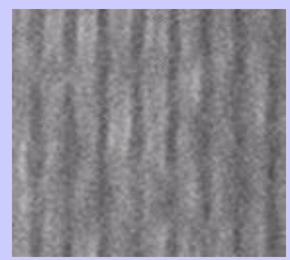
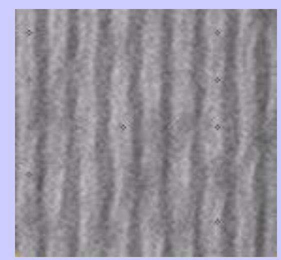
Process Improvements: Resist N

18nm Half-Pitch, Bi-Convex Dipole Illumination

Control	TMAH / Top Coat	TBAH / FIRM™ Extreme™ 10	TBAH / FIRM™ Extreme™ 10 / Top Coat
			

- Control condition with TMAH developer has significant “matting”
- Small improvement with TMAH developer and topcoat, and TBAH developer and topcoat
- Significant improvement with the combination of TBAH/FIRM™/Topcoat

Process Improvements with Resist O
18nm Half-Pitch, Bi-Convex Dipole Illumination

	Control	FIRM™ Extreme™ 10	FIRM™ Extreme™ 12	FIRM™ Extreme™ 10 / Top Coat
TMAH				
TBAH				

- TMAH, with and without FIRM has significant “matting”
- Topcoat improves imaging with both TMAH and TBAH developer

Agenda

- Line/space with bi-convex dipole
- **Contact and via**
  - **Imaging comparison on LBNL MET tool**
  - **Exposure tool for detailed evaluation: ADT**
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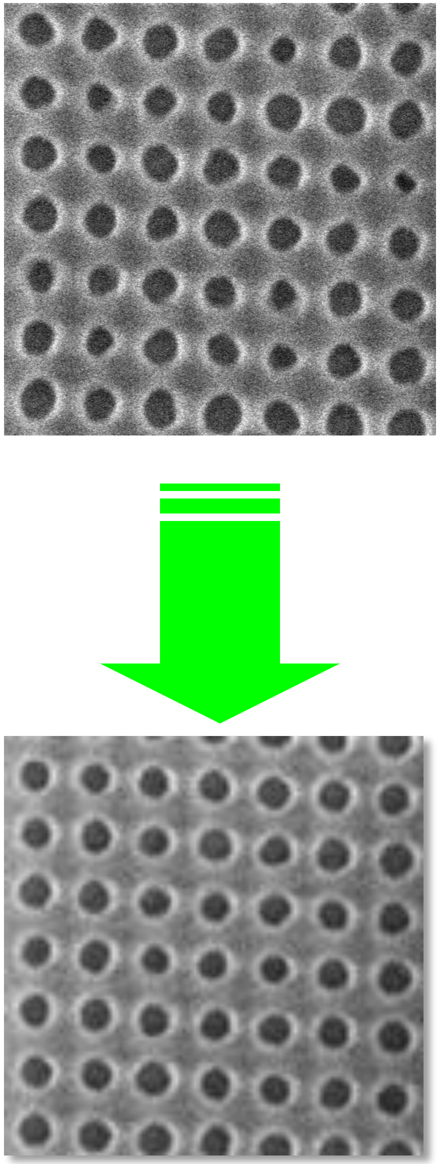
Contact hole imaging

- Issues
  - Sensitivity
  - Local CDU
  - Circularity
  - Contact edge roughness
- Possible Causes
  - Shortage of EUV photons
  - Shot noise
  - MEEF
  - Stochastics

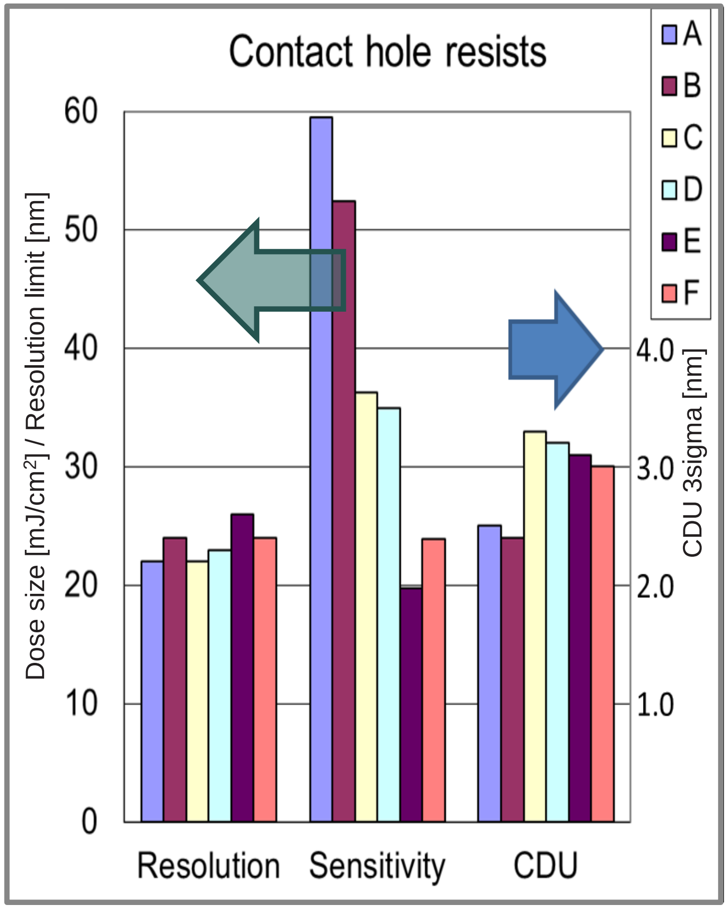
Mitigation Strategies

- Biased reticle
  - Sensitivity improvement
  - Local CDU improvement
  - Resolution improvement
- Post-process techniques
  - Improves contact edge roughness (CER)



Contact Hole imaging on the LBNL MET tool

Berkeley MET
Quad, NA 0.3, sigma 0.48~0.68
FT 80nm
Underlayers
No mask bias



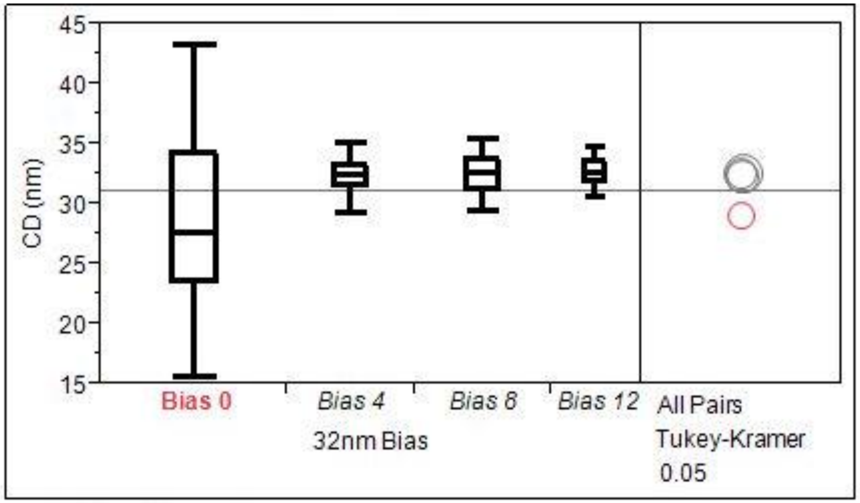
* CDU was measured at 26nm HP

	28nm	26nm	24nm	23nm	22nm	21nm	20nm
A							59.5mJ/cm^2 2.5nm
B							52.4mJ/cm^2 2.4nm
C							36.3mJ/cm^2 3.3nm
D							35.0mJ/cm^2 3.2nm
E							19.8mJ/cm^2 3.1nm
F							23.9mJ/cm^2 3.0nm

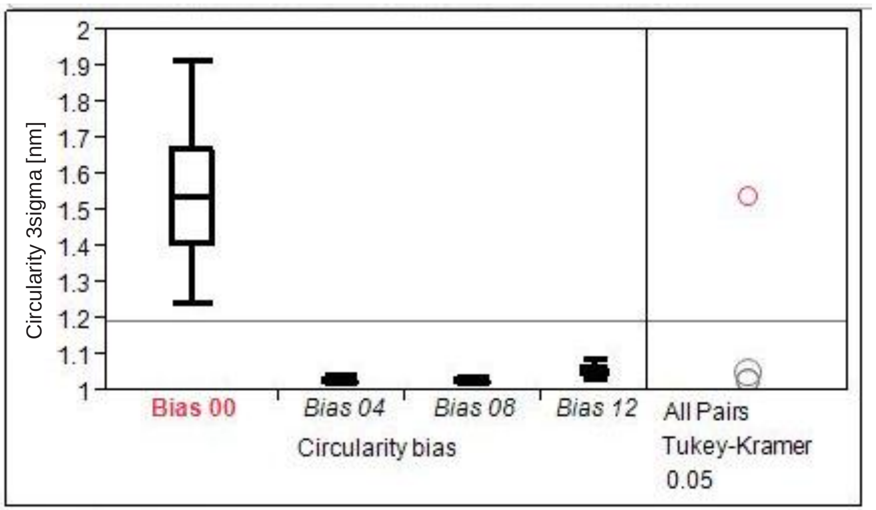
Dose size [mJ/cm^2] / LWR [nm]

Resist P Contact Hole Variability, 32nm

Local CDU



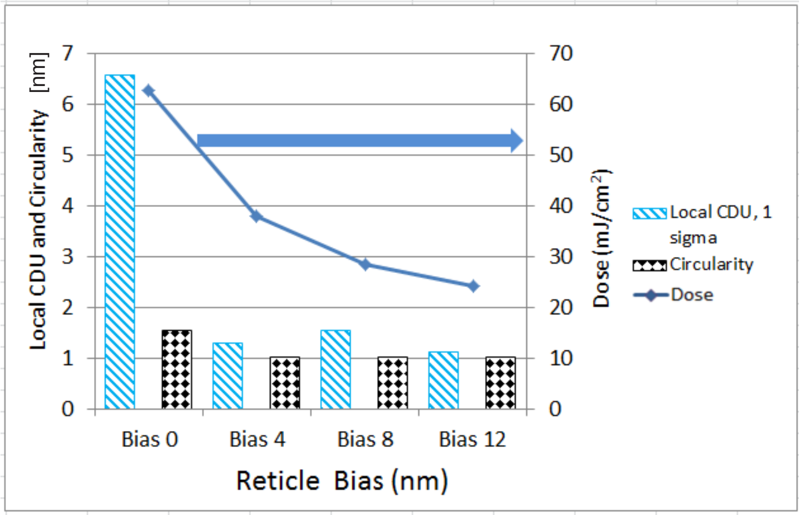
Circularity



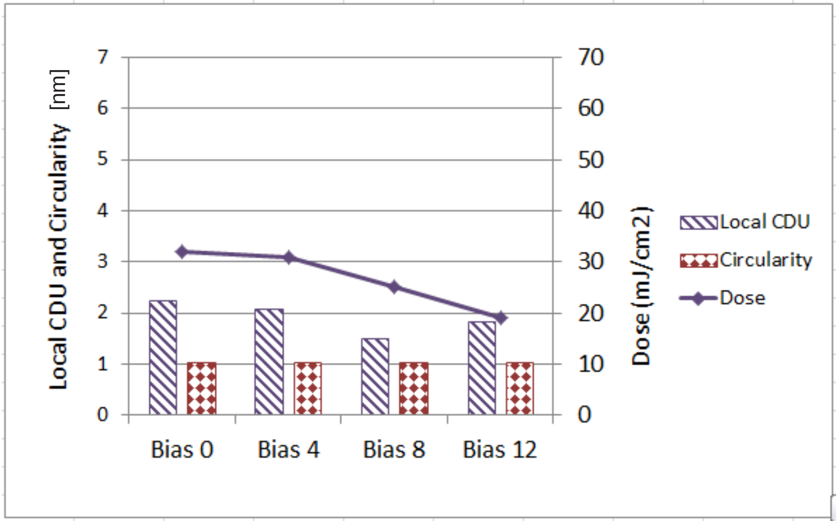
4, 8, and 12nm Bias are significantly better for local CDU, circularity, and variability of circularity

Lithographic Comparison for 3 resists

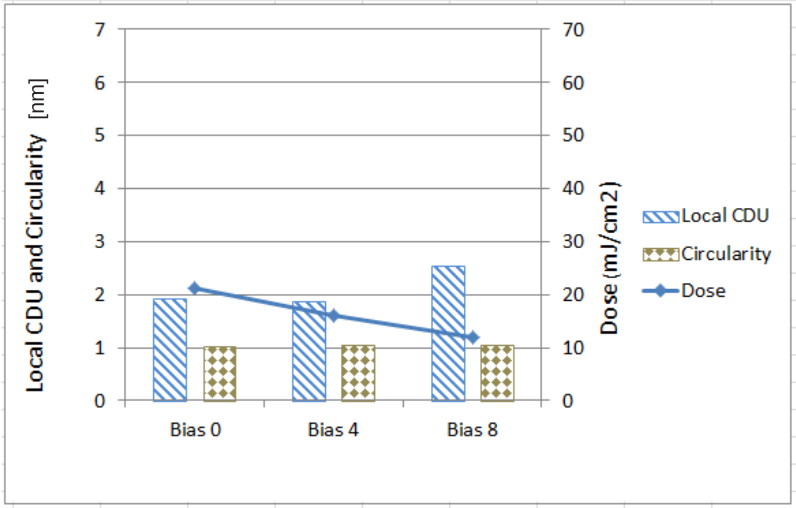
Resist P



Resist N

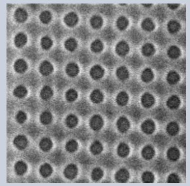
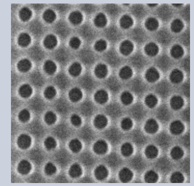
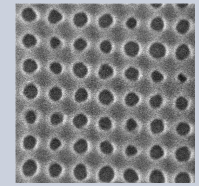
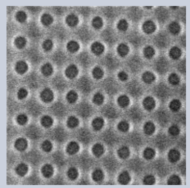
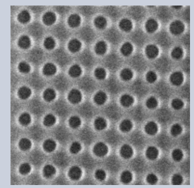
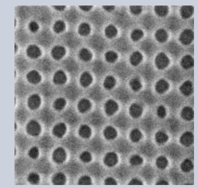
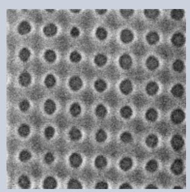
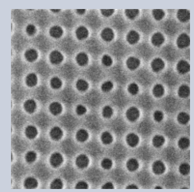
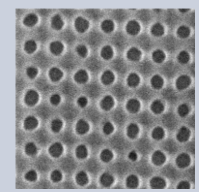


Resist S



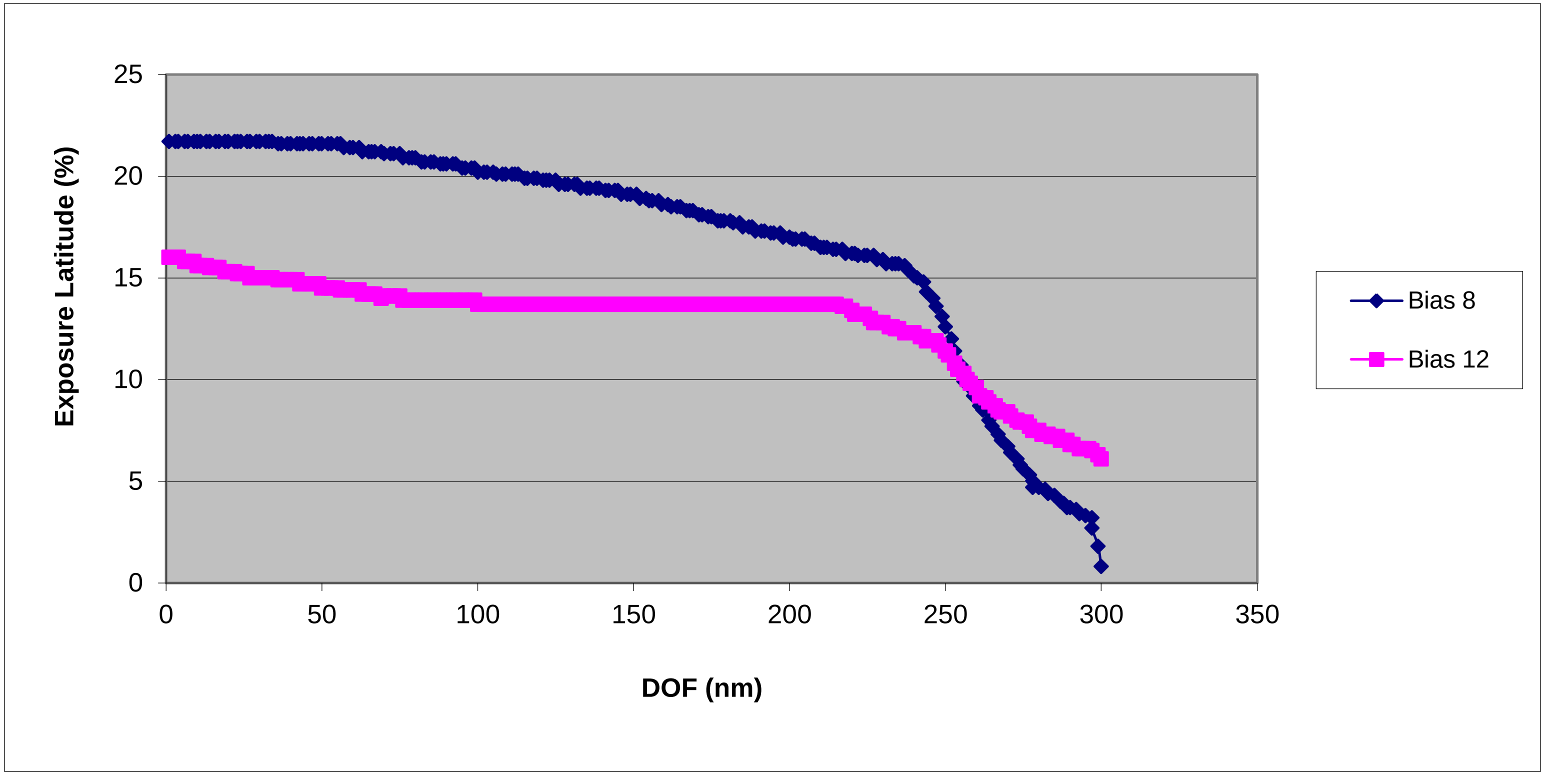
- Local CDU:
  - Resist P has improved local CDU with bias of ≥4
  - Bias8 looks appropriate for Resist N.
- Circularity is similar on all resists
- Photospeed improves with bias for all resists

Image comparison of 3 resists

	Resist P	Resist N	Resist S
Image Mask Bias: 8nm Focus: 0um			
Dose size	29 mJ	25 mJ	12 mJ
Image Mask Bias: 4nm Focus: 0um			
Dose size	38 mJ	31 mJ	16 mJ
Image Mask Bias: 0nm Focus: 0um			
Dose size	62 mJ	32 mJ	21 mJ

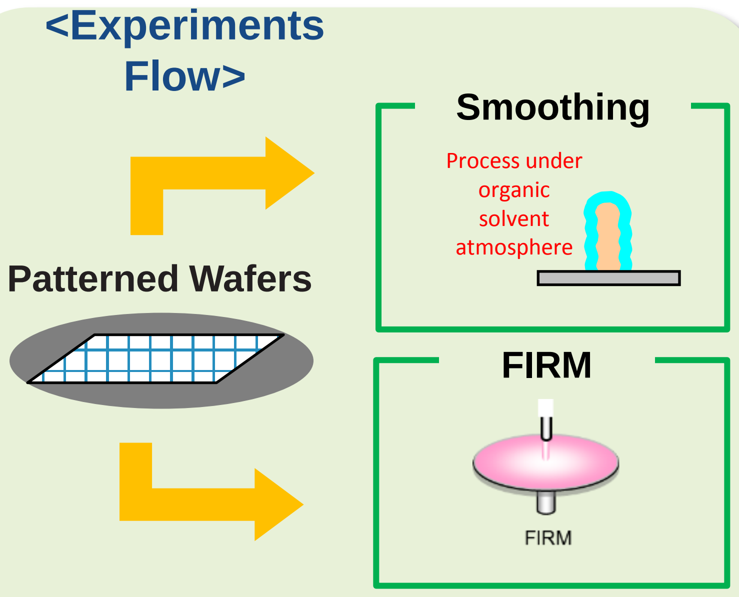
- Resist P has best local CDU, at the expense of photospeed.
- Resist N has intermediate photospeed and similar CDU to resist P
- Resist S has the best photospeed, but at the expense of local CDU

Process window for resist N
8 and 12 nm biases



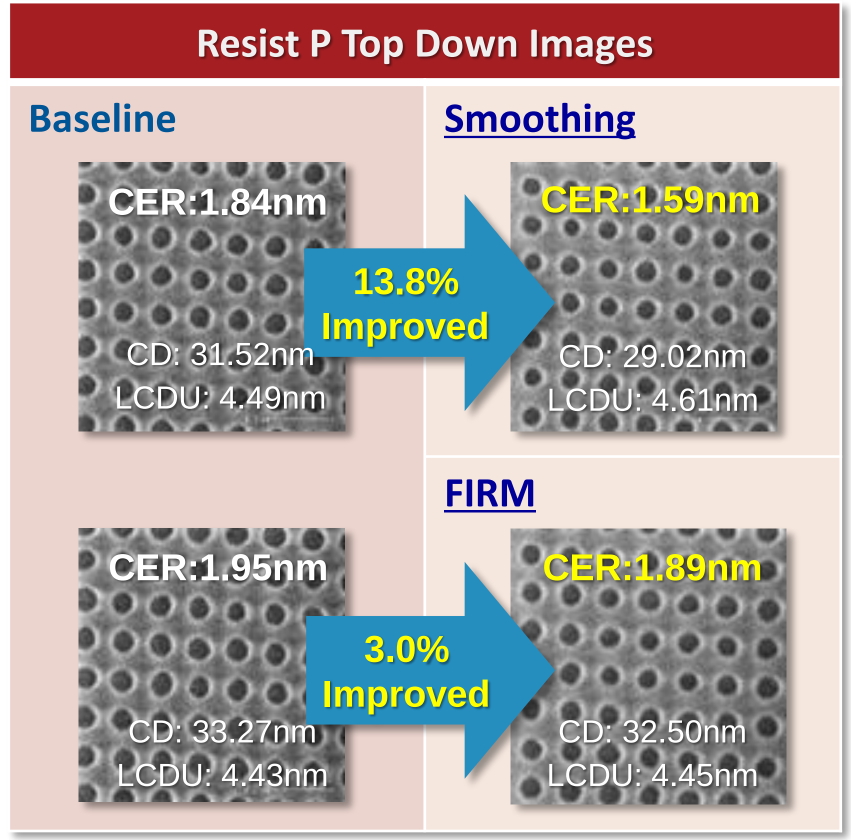
- Process window needs to be taken into account when choosing correct bias
  - DOF is similar at 10% EL
  - 8 nm bias has larger total DOF

TEL Contact Smoothing Data, Resist P



<Experiment Conditions>

Track : CLEAN TRACK ACT™12
CLEAN TRACK ™ LITHIUS Pro™ V
Exposure: ASML Alpha Demo Tool

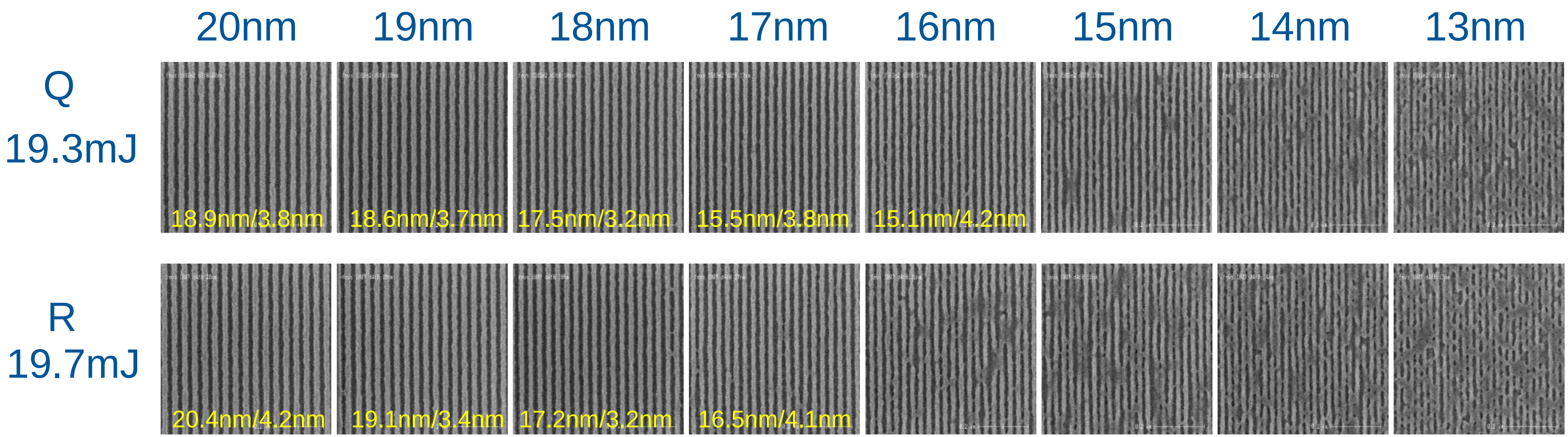


- Smoothing and FIRM rinse are verified to contribute CER improvement for contact hole feature.

Agenda

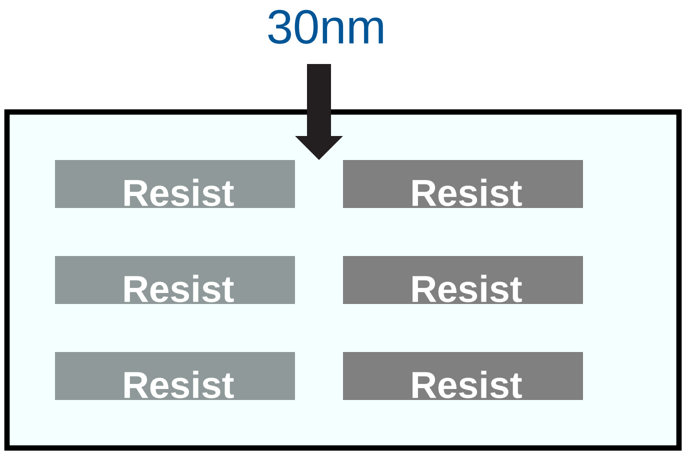
- Line/space with bi-convex dipole
- Contact and via on ADT
- **2D imaging**
  - **Imaging comparison on LBNL MET tool**
  - **Exposure tool for detailed evaluation: Albany MET**
- LWR and pattern collapse improvement
- Defect reduction

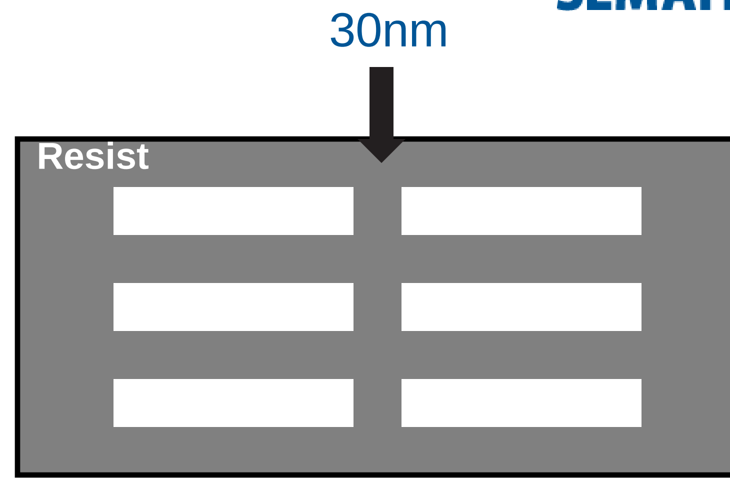
High resolution materials (based on LBNL exposures)



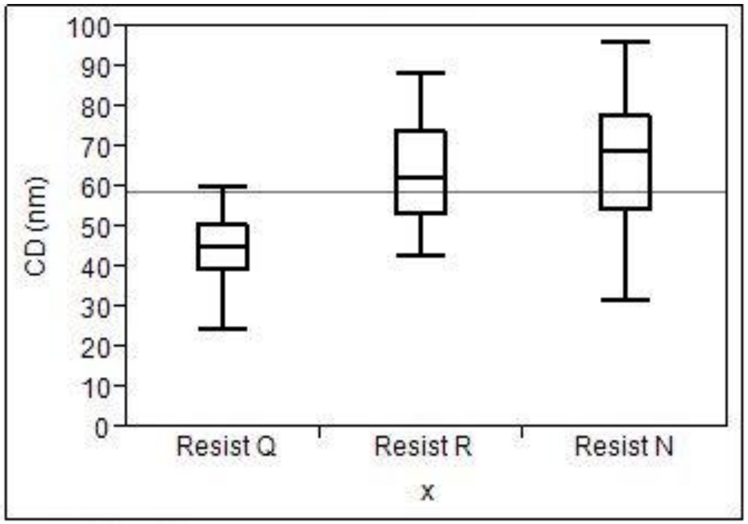
- Z factor is 5.2e-9 for Q
- Z factor is 6.5e-9 for R
- Both materials have high performance for L/S applications
- Evaluated for line end performance

Material performance for 2-D imaging

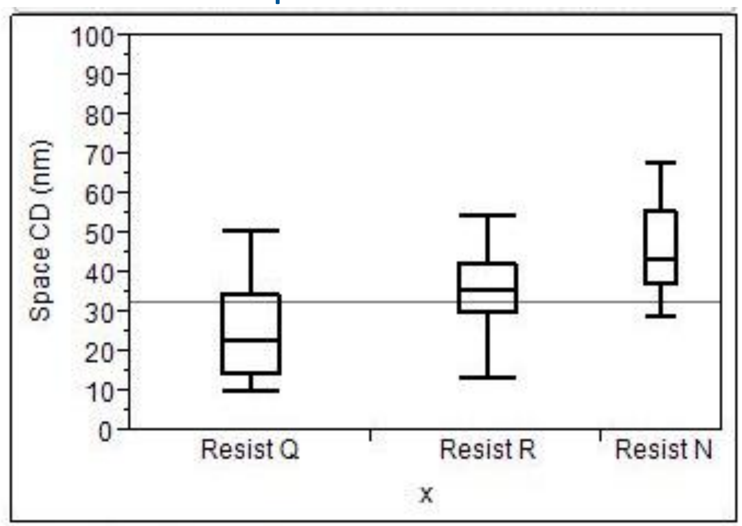




Line end



Space end



Line and space end performance is an attribute that needs further improvement

Agenda

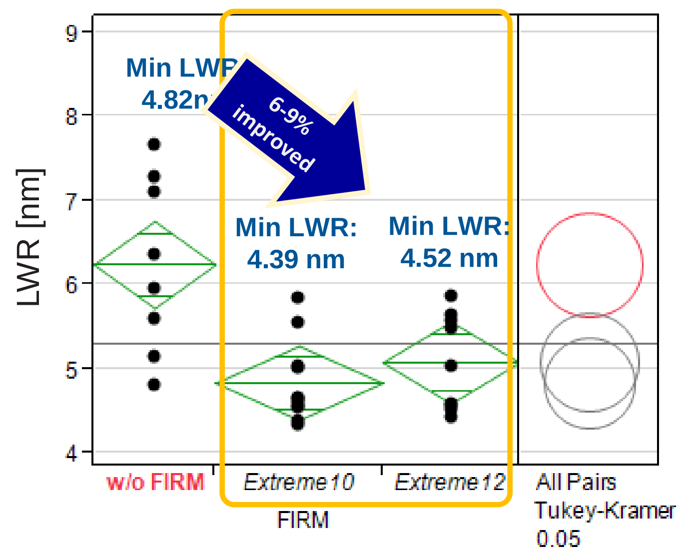
- Line/space with bi-convex dipole
- Contact and via applications
- 2D imaging
- **LWR and pattern collapse improvement**
  - **Exposure tool: ADT and Albany MET**
- Defect reduction

Pattern Collapse Margin with FIRM Rinse

<Over Dose Line Pattern Collapse Margin at 26nmhp>

w/o FIRM	Dose [mJ/cm^2]	13.00	14.00	15.00	16.00	17.00	18.00
	Image			22.85 nm	Collapse		
Extreme10	Dose [mJ/cm^2]	12.65	13.70	14.75	15.80	16.85	17.90
	Image						21.43 nm
Extreme12	Dose [mJ/cm^2]	12.20	13.30	14.40	15.50	16.60	
	Image				22.42 nm	Collapse	

<One way ANOVA>

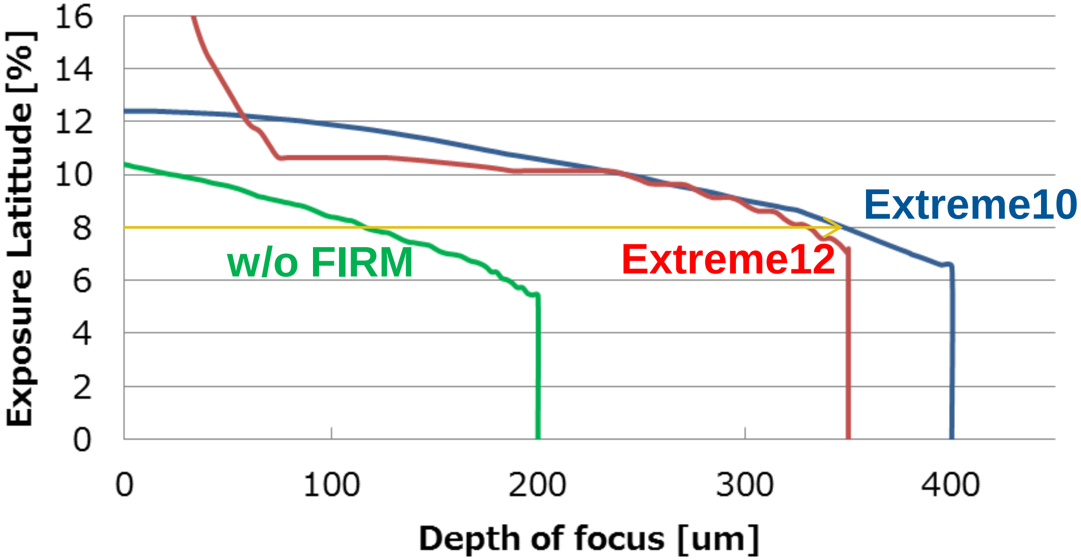


- Extreme™ 10 and 12 show improvement of line pattern collapse margin from w/o FIRM.
- LWR can be improved by 6-9% using FIRM rinse.

Albany MET

Process Window for Resist T with FIRM Rinse

<Comparison of PW by w/o FIRM and w/ FIRM>

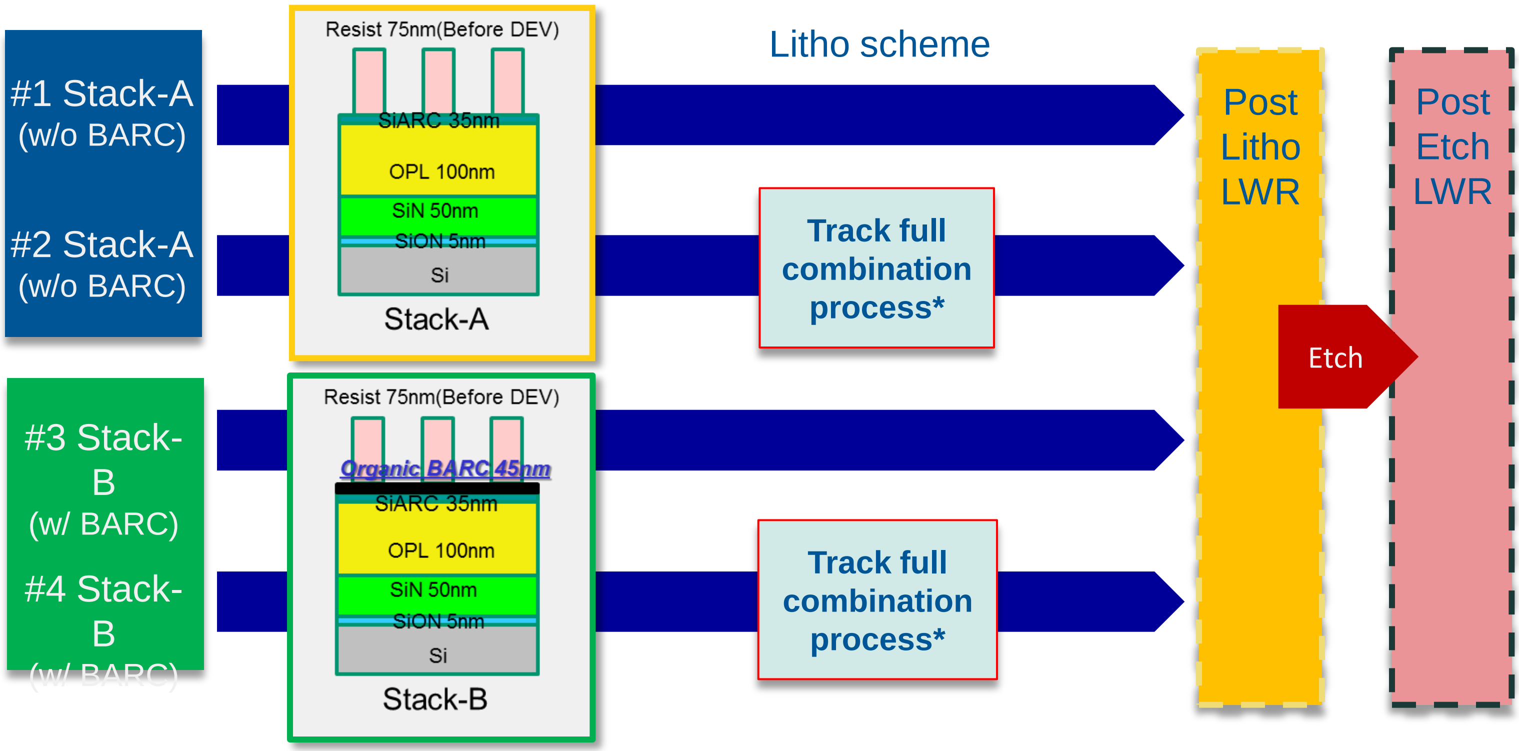


	DOF at 8% EL [nm]	Improved [%]
w/o FIRM	117	-
Extreme10	348	222%
Extreme12	331	211%

- Extreme™ 10 and 12 improved process margin, which at 8% EL is over 300nm of DOF.

Thru-Etch Test w/ Organic BARC

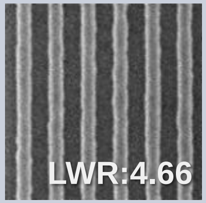
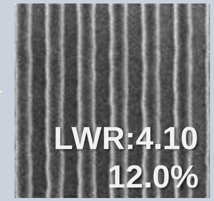
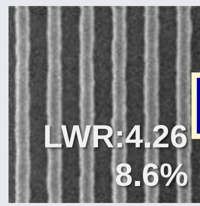
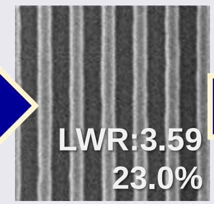
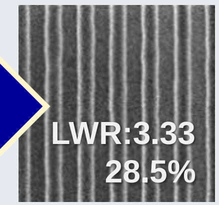
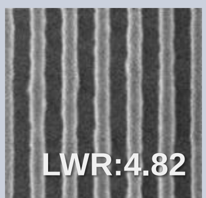
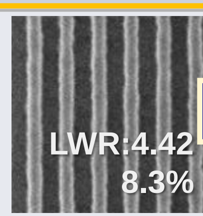
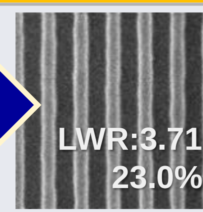
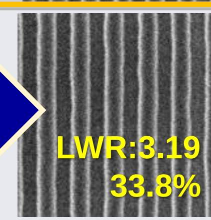
- **Experiments Process Flow**



* Track full combination process:
Developer optimization + FIRM rinse + Smoothing process

《Process condition》
Resist: SEMATECH POR Resist
Film thickness: 75nm
Mask CD: 32nm Line 1:1
DEV: TMAH

Thru-Etch Test Result

	Baseline	Developer process optimization and FIRM	Smoothing	Etch smoothing
#1 Stack-A (w/o BARC)	 LWR:4.66	12.0% →		 LWR:4.10 12.0%
#2 Stack-A (w/o BARC)	8.6% ↘	 LWR:4.26 8.6% 14.4% →	 LWR:3.59 23.0% 4.8% →	 LWR:3.33 28.5%
#3 Stack-B (w/ BARC)	 LWR:4.82	25.7% →		 LWR:3.58 25.7%
#4 Stack-B (w/ BARC)	8.3% ↘	 LWR:4.42 8.3% 14.7% →	 LWR:3.71 23.0% 10.8% →	 LWR:3.19 33.8%

(nm)

- Both Stack-A and B full combination process show over 28% improvement.
- Stack-B full combination process delivers best LWR improvement 34%.
- w/ BARC process gives better improvement for Etch smoothing.

Agenda

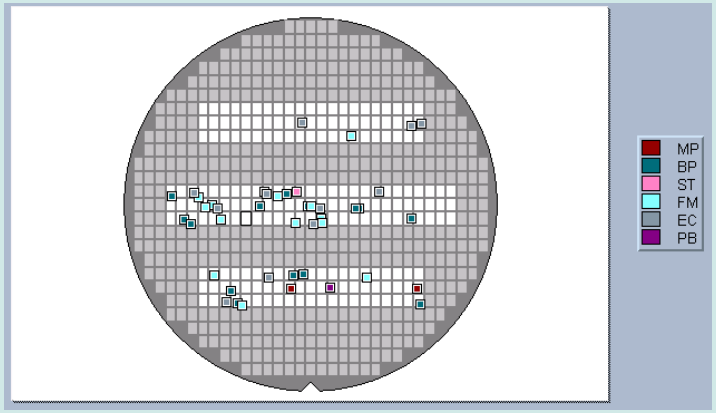
- Line/space with bi-convex dipole
- Contact and via on ADT
- 2D imaging
- LWR and pattern collapse improvement
- **Defect reduction**
  - **Exposure tool: ADT**

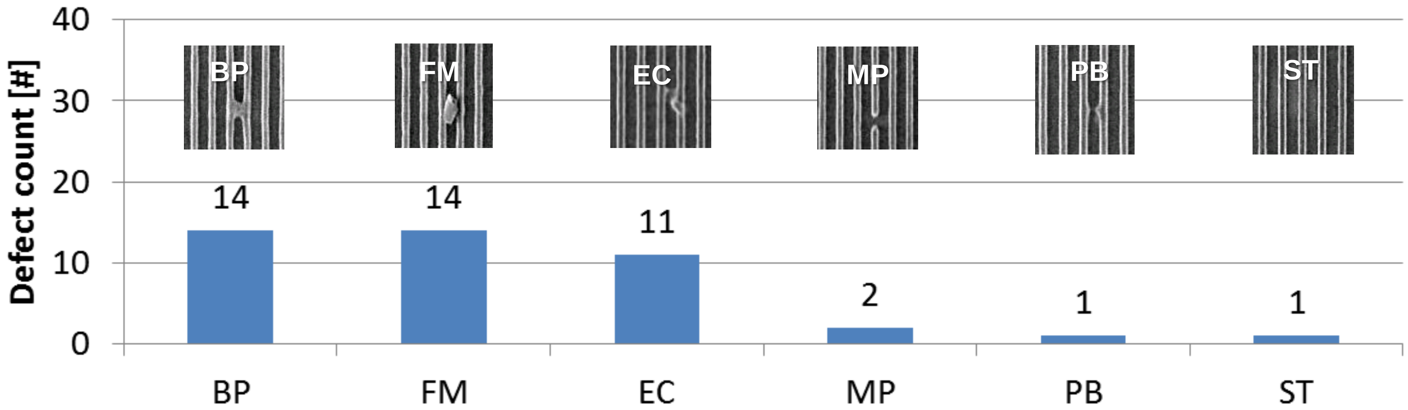
TEL Defect data from KLA2835

- Resist N

MGP TMAH w/ Extreme™ 10
(Resist N on Tri-layer stack)

- Defect: 43 [counts]
- Defect Density: 0.55 [count/cm^2]





BP : Bridge Pattern
FM : Foreign Material
EC : Embedded Contamination
MP: Missing Pattern
PB : Partial Bridge Pattern
ST : Stain Defect
NV : Non Visible

- D.D. 0.55 count/cm^2 had achieved with high sensitive measurement

Summary

- High resolution imaging can be improved using bi-convex dipole illumination by applying FIRM techniques combined with alternate developer and topcoat
- Contact hole printing is hampered by local CDU and circularity
  - Both can be improved using the appropriate reticle bias
  - Contact edge roughness can be improved by smoothing
- 2D imaging needs to be studied more thoroughly
  - Even the most promising materials require better tip-to-tip performance
- LWR and pattern collapse are improved with track-based post-processing
  - LWR improves by ~34% with FIRM, smoothing, and etch-based techniques
  - FIRM Extreme™ 10 & 12 both improve the collapse margin and resist T process
- Defects are monitored continuously; they are primarily bridging, foreign material, and embedded contamination

Acknowledgements

- RMDC team
- LBNL staff
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